Palm Beach County
Chain of Lakes Water Quality Report

2006-2008

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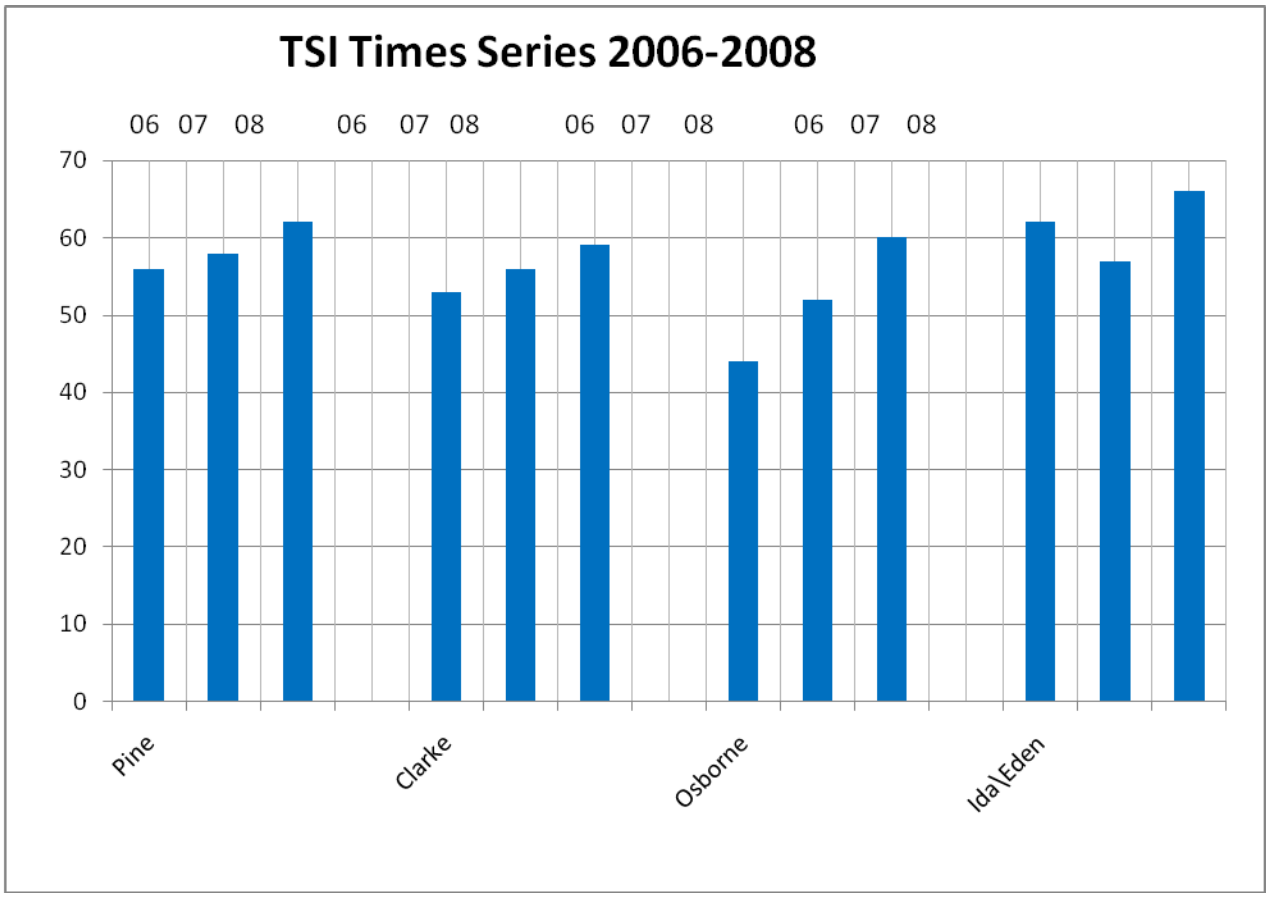
I. Executive Summary

The Chain of Lakes is located on the western slope of the Atlantic Coastal Ridge in Palm Beach County and run north and south for approximately 30 miles. The northern most portion starts at Belvedere Road in West Palm Beach to Lake Ida Road in southern Boynton Beach and has been divided into four water body segments for this water quality monitoring project. The water bodies are: Pine Lake, Lake Clarke, Lake Osborne, and Lakes Eden and Ida combined. These water bodies were once natural freshwater slough systems but to accommodate development the lakes and adjacent wetlands marshes were dredged and filled extensively for flood control. Currently the lakes are also used for boating, fishing, and other recreational activities. While they are lake systems, the hydrology is atypical of a lake/watershed regime, due to the interconnection with the Central and Southern Flood Control Project and the Lake Worth Drainage District (LWDD). Water levels in the lakes are controlled artificially by the series of canals and water control structures maintained by the South Florida Water Management District (SFWMD) and the LWDD. The lakes are part of three interconnected basins as defined by the SFWMD: C-51 East, C-16, and C-15 (SFWMD Technical Memorandum, June 1988). The C-51 Canal and the LWDD E-4 Canal typically have the greatest influence on the lake's water stages, water flow, and water quality. Water quality is impacted by the drainage of approximately 1,000 miles of canals that wash nutrients and other pollutants into the lakes and ultimately to the ocean via the SFWMD control structures. The goal of lake management is to provide for the preservation, maintenance, and restoration of the chain-of-lakes system. The water quality monitoring program was designed to provide information to the managers to achieve the lakes management goals. Monitoring began in January 2006 and continues today. Thirteen monitoring stations are sampled bi-monthly for a wide variety of parameters, including field measurements. See Map 1 for stations and page 6 for parameters. This report provides the assessment of water quality data from January 2006 to December 2008.

Nutrients as nitrogen and phosphorus can be the most common pollutants to cause water quality degradation. Lake scientists have developed a scale for evaluating the extent of reduced water quality or degradation called the Trophic State Index (TSI). The Florida Department of Environmental Protection (FDEP) has established by Rule the TSI value that represents extreme degradation or "Impaired" water quality. For the Chain of Lakes the value is a TSI of 60 or higher. The calculated yearly TSI for the COL can not only give us a snapshot in time evaluation of water quality but allow managers to use trend analyses for long term assessments and predictions. All of the four lakes in the chain are showing yearly increasing TSI values since 2006, with Pine Lake, Lake Osborne, and Eden/Ida currently above 60 and "impaired" for nutrients. See Figure 1. A pollutant loading evaluation conducted by Environmental Research and Design, Inc. (2002) determined that the primary nutrient source(s) and runoff are carried into the lakes through the canal systems. Although Lake Clarke has not reached the critical TSI number of 60, the lake has jumped from a TSI of 53 in 2006 to 58.9 in 2008. Presently the detrimental effects of high TSI have not frequently been observed in the COL but this could occur in the nearer future if the nutrient inputs are not reduced. Adverse effects such as frequent algal blooms and depleted dissolved oxygen may occur for the COL if management efforts do not include reducing the nutrient concentrations currently observed. Monitoring needs to continue so trend analysis for the lakes and canal systems can be utilized in formulating good management decisions.

Fecal coliform bacteria were collected at all stations for the three years. Fecal coliforms come from the digestive tract of warm-blooded animals and historically have been used as an indicator for the potential of human pathogens in water. Coliforms can enter the water from many sources, including direct deposit, stormwater runoff, and septic systems. Results indicate that most of the lakes have sporadic extremely elevated fecal coliform numbers. A definitive source cannot be established, due to the temporal nature of the concentrations. But because of the high concentrations human health issues are a concern and further investigation is warranted.

Figure 1. Chain-of-Lakes TSI Time Series.



In general, the Chain-of-Lakes show increasing nutrient loadings as indicated by the TSI trends. Lake Ida and Pine Lake are currently listed as impaired for nutrients (TSI) by the Florida Department of Environmental Protection. Increases in organic nitrogen concentrations were observed in all lakes, while concentrations of total phosphorus declined.

II. Introduction

The information collected will assist managers to address problems and provide the information necessary for preservation and restoration. The Chain of Lakes water quality monitoring projects are designed to gather information on the chemical, physical, and biological parameters of the lake systems.

The Chain of Lakes includes Pine, Clarke, Osborne, Ida, and Eden and are located near the toe of western slope of the Atlantic Coastal Ridge in Palm Beach County. The Chain of Lakes runs north and south approximately 30 linear miles. Prior to 1900, the chain-of-lakes was part of an extensive wetland slough system west of the Coastal Ridge. They are classified as Class III Freshwater lakes under the Florida's Criteria for Surface Water Quality Classifications, Chapter 62.302 F.A.C. The classification lists the intended used of the water bodies as for recreation, propagation and maintenance of a healthy, well-balanced population of fish and wildlife. Besides movement of water for flood control, the lakes and the associated Lake Worth Drainage District (LWDD) E-4 Canal are used extensively for boating, fishing and other recreation activities. However, the lakes are also an integral part of the drainage system for central and southern Palm Beach County. While they are lakes, the hydrology is atypical of a lake/watershed regime, due to the interconnection with the Central and Southern Flood Control Project and the LWDD. Water levels in the lakes are controlled artificially by the series of canals and water control structures maintained by the South Florida Water Management District and the LWDD. See Map 1 below for sampling locations.

Pollutant Sources

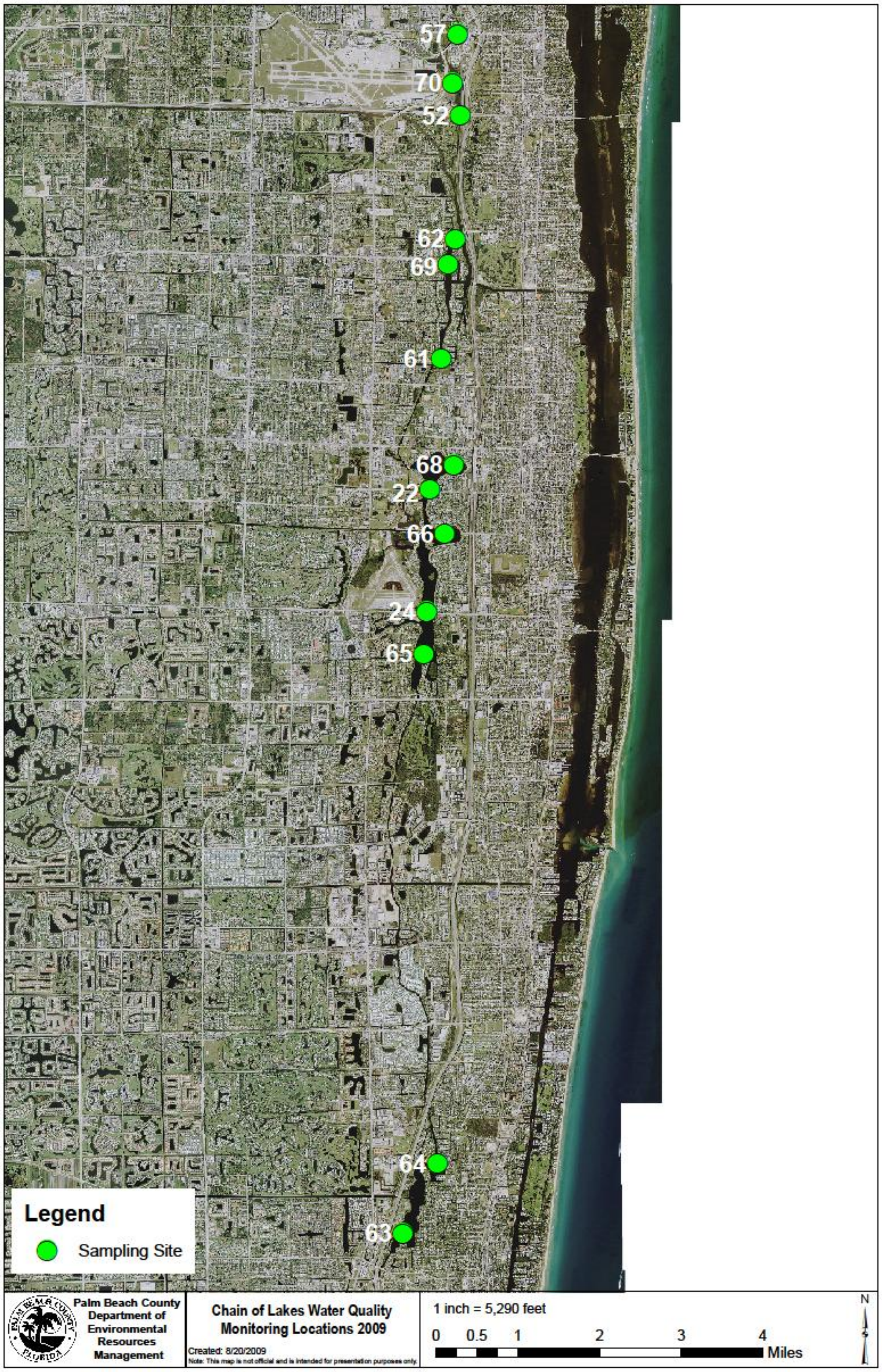
Watershed boundaries for the Chain of Lakes are largely artificial due to the extensive canal systems which interact with each lake. As a result, calculated drainage basin to lake area ratios is extremely high for each of the five lakes. As a rule, lakes with high basin/lake area ratios are considered to have a significant influence from the contributing sub-basin areas. In other words, the lakes are heavily impacted by basin surface water run-off, e.g., stormwater runoff, and hydraulic movement within the canals. Stormwater runoff can heavily impact Florida lakes, streams, estuaries and the ocean with nutrient, organic chemicals, and pathogens. See Table 1, for COL basin physical characteristics.

Table 1. Morphology and Basin Characteristics

Parameter	Units	Pine	Clarke	Osborne	Ida	Eden
Lake Surface Area	acres	34.8	56.5	378	121	49.0
Lake Volume	ac-ft	227	275	2,065	743	349
Mean Depth	ft	7.6	7.8	6.8	8.2	11.5
Maximum Depth	ft	17.1	17.4	27.0	19.8	19.8
Shoreline Length	ft	7301	17623	94904	26686	24712
Drainage Basin	--	C-51 (east sub-basin)	C-51	C-16	C-15	C-15
Drainage Area	acres	104,996	104,996	40,011	47,470	47,420
Drainage Basin/ Lake Area Ratio	--	3,016	1,858	106	392	968

Source: State of Lakes Report, PBC-ERM, 1997.

Map 1. Chain of Lakes overall location and sampling stations.



The Palm Beach County Chain of Lakes Water Quality and Pollutant Loading Evaluation (Environmental Research & Design, Inc., May 2002) ERD, ERD Report provided an in-depth assessment of the pollutant sources and analyses related to the drainage basin/lake area issue. The sources of pollutant loading were identified as; tributary inflow (canals), seepage inflow (groundwater), precipitation and miscellaneous storm water outfall inputs (drainage pipes). The 2002 evaluation identified the primary pollutant loading source as tributary inflow, with the C-51 Canal as the primary source for Pine Lake, and lakes Clark and Osborne. The LWDD tributary canals were identified as the primary source for lakes Ida and Eden.

The potential for water pollutant sources to enter the Chain of Lakes are numerous; including, nutrients, pesticides, heavy metals and bacteria from stormwater runoff. The primary pollutants within the Chain-of-Lakes are excessive nutrients. Excessive loadings of nutrients, nitrogen and phosphorus, usually lead to eutrophication. A eutrophic lake has high nutrient levels and associated high primary productivity, which is the production of organic compounds. Eutrophic lakes are subject to excessive algal blooms, resulting in poor water clarity and other associated water quality problems, such as low dissolved oxygen.

Study Design

This three year water quality update is based on data provided by two water quality monitoring programs; The Chain of Lakes Water Quality Monitoring Program comprised of 12 sites shown on Maps 2, 3, 4, and 5, and the National Pollutant Discharge Elimination System Monitoring Program (NPDES) which has two sites located in Lake Osborne (Map 4, Sites 22 and 24). For more information on the NPDES program, see www.co.palm-beach.fl.us/erm/permitting/water-resources/surface-storm-water. The Chain of Lakes Water Quality Monitoring Program began sampling in January 2006, and the NPDES monitoring program has been on-going since 1998. The sampling frequencies for both are bimonthly, or 6 monitoring events conducted annually.

Chemical and microbiological samples were analyzed by the contract laboratory Genapure (formerly U.S. Biosystems) in Boca Raton, Florida. Genapure is a nationally, (NELAC), and the State of Florida (DoH) accredited laboratory. All laboratory results were reviewed by the laboratory's Quality Assurance/ Quality Control (QA/QC) officer before being forwarded to the Department of Environmental Resources Management (ERM). ERM performed a QA/QC audit on all results to verify accuracy and validity before any data evaluation of water quality. Data that did not pass the QA/QC criteria as identified pursuant to Rule 62-4.246, F.A.C., were not used in the evaluations. The QA/QC reports provided by the laboratory were reviewed, as well as ERM conducting an internal review of the methods, detection limits, and holding times for the samples.

A statistical analysis was conducted using the software program "SigmaStat 3.1 (SPSS Corp, 2001). The data analyses will include, "data range", "median" and "geomean". References to state standards and background conditions will be considered where applicable. Results are in milligrams per liter (mg/l) except pH which is standard units (range 0-14) and coliforms as 100/cfu (colony forming units).

The Chain of Lakes run north and south from Belvedere Road in West Palm Beach to Lake Ida Road in Delray Beach and located in three SFWMD designated basins. Evaluations will be determined on each lake separately. There are thirteen sampling stations selected throughout the COL. For this report water quality monitoring began in January 2006 and continued bimonthly through December 2008. Station 67 was not included in the overall study as it was originally selected as a special project site (Square Lake) and was not a representative Chain of Lakes site; Site 67 was discontinued in 2006. Segment maps and sampling stations are shown below.

On each monitoring date, field measurements were collected for dissolved oxygen, pH, specific conductivity, and temperature. Pre-cleaned bottles were used to collect water chemistry samples for laboratory analyses, preserved as required and placed in a cooler on ice for delivery to the laboratory. Laboratory results were electronically submitted to PBC-ERM. Only data that passed both laboratory and ERM QC checks were used in this study. Raw data are copious and therefore not included in this report but are in the Florida STORET water quality database or by contacting ERM staff.

The water quality monitoring parameters used for the Chain of Lakes and NPDES sites are:

Field Measured (Physical)

- Dissolved Oxygen
- pH
- Specific Conductivity
- Temperature
- Secchi depth (discontinued in early 2006)

Laboratory Analysis

- Total Kjeldahl Nitrogen (summation of organic nitrogen and ammonia)
- Ammonia
- Nitrate
- Nitrite
- Total Phosphorus
- Ortho-Phosphorus (dissolved form)
- Chlorophyll a, corrected for phaeophytin (indicator of algal production)
- Turbidity
- Total Hardness (as $CaCO_3$)
- Total Suspended Solids (TSS)
- Fecal Coliform Bacteria
- Metals: As, Cd, Cu, Pb, Zn

Metal sampling was discontinued starting December 2007 when data indicated results were at detection limit or at values much lower than water quality State Standards for metals of concern.

III. Methodology to Determine Water Quality Status

Water quality assessments will be determined based on the general understanding of Limnology (study of lakes) and the application of the Florida State Water Quality Standards for Class III waters F.A.C. 62.302. The Rule is used for interpretation and indicating any violations per meeting their designated usage. The Impaired Water Rule, F.A.C. 62.303 (IWR) is applied by the State to identify impaired waters. If a water body is deemed impaired then a Total Maximum Daily Load (TMDL) Rule is adopted. The Tropic State Index (TSI) and Chlorophyll a are just two of the metric that are important in the assessments. Additional water quality evaluations to determine impairment can include coliform bacteria, suspended solids/turbidity, and dissolved nutrients.

Trophic State Index (TSI)

The TSI is a mathematical formula used to estimate the trophic state of any freshwater lake. The trophic state is an indication of general health and aging of lake. Total nitrogen and total phosphorus are the nutrients of concern in the trophic state calculations. Increasing nutrient loadings for surface water flow and runoff and internal nutrient cycling are the basic dynamics behind this process. The general public would describe a young lake as "clean" and an old lake as "dying" or stagnate with excessive plant and algal growth. All lakes age over time and in Florida the average lake completes the cycle in approximately 150 years. This process is called Eutrophication. To a Limnologist, lakes age by becoming more energy productive as populations of plant and animals increase, and interact in more complex food webs. Increased or excessive productivity can speed up the normal aging and eventually "kill" the lake. The increased productively is driven by increased loadings of total nitrogen (TN) and/or total phosphorus (TP). Increase in chlorophyll-a, e.g. algal growth, is a direct response to this productivity. Massive algal blooms can dramatically upset the normal functions within the lake and negatively impact the recreational benefits provided, as well as being a potential detriment to human health. As this usually has an anthropogenic cause and is not considered normal for any lake system, efforts must be made to reduce the negative impacts of the causative agents, the nutrients. The stages of the eutrophication or aging process within lakes are defined by the TSI number. TSI calculations include the parameters: TN, TP, and Chlorophyll-a (chl-a) concentrations. The method of calculation has been published in the Florida Department of Environmental Protection (DEP) document, "The State of Florida Waters Integrated Assessment 305(b) Report, 1996." The TSI scale runs from 0 – 100+ with the higher the number indicating the more productive (older) the lake. The FDEP considers the TSI value and the color of the water when applying the IWR to lakes. If a relatively clear lake, color less than 40 platinum cobalt units (pcu), has a TSI exceeding 40 then it is considered impaired. Lakes with color of greater than 40 units, and the TSI is 60 or more, is considered impaired. Color was not analyzed in this study, but previous sampling identifies the col as having a color greater than 40 pcu.

Chlorophyll-a, Dissolved Nutrients, and Nutrient Limiting Factors

Although chlorophyll a and the dissolved nutrients are functions within the TSI evaluations, these parameters can assist in additional water quality evaluations in their own right. Chl-a can indicate the level of direct impairment due to nutrient enrichment especially when viewed temporally. A chl-a impairment numeric scale has been developed by lake scientists. Chlorophyll- a concentrations, in mg/M^3, from 0-39 represents lakes with small to moderate nutrient loadings, from 40-90 algal bloom are frequent and represent moderate to heavy inputs of nutrients, and 90 or higher represents excessive nutrient inputs are can results in catastrophic algae bloom and algae die-off which can deplete the lake of oxygen. Lakes with continuous chl-a values of >60 are considered Hypereutrophic lakes and represent a dying out-of-control system with low DO and dramatically reduced species diversity. It has been generally accepted by Lake Managers when a lake is in the Hypereutrophic state only major and dramatic restoration step can bring it back to a healthy system, if at all.

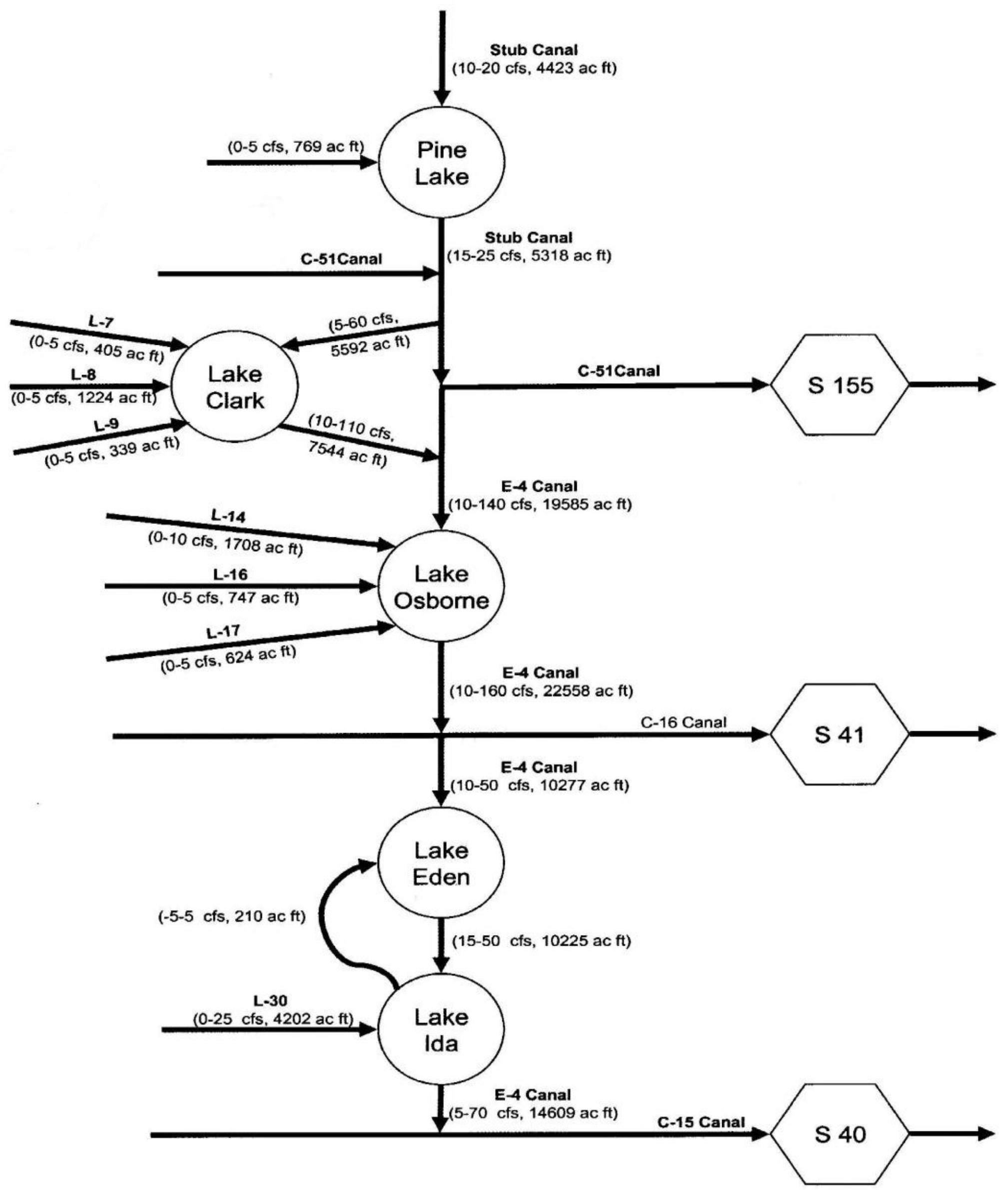
The TSI calculation also identifies the nutrient "limiting factor", that is, the nutrient that drives the eutrophication of the lake. This nutrient, as the limiting factor, is the nutrient that is in insufficient concentrations and any additional increase will cause productivity to increase beyond healthy limits. Therefore, targeting the limiting nutrient for load reduction to the lake is the best management strategy. In some instances the nutrients represent loading from the re-suspension of lake sediment.

Hydrology

The Chain of Lakes is part of an extensive canal system designed and used for drainage and flood control. The existing hydrologic regime of the Chain of Lakes is quite complex and is regulated by a number of man-made canals and water structures. (See Figure 2 and 3 for hydrological schematics for the Chain of Lakes.) The magnitude and direction of water movement in both Pine Lake and Lake Clarke are regulated to a great part by operations schedules of the C-51. Lake Osborne is located within the C-16 basin but is influenced by the E-4 Canal which connects to the north and south of the lake. Water can travel both north and south, but generally moves in the southerly direction due to southerly flow of the E-4 Canal. Surface water may flow to the C-16 Canal and to the S-41 Structure and into the Lagoon, if the S-41 Structure is open. Lake Eden and Ida are located in the C-15 basin. Although the primary flow pattern is north to south, water can travel north via the E-4 to the Boynton Canal and by tide out the S-41, or south via the E-4 to the Delray Canal, the C-15, and out to tide through the S-40 structure.

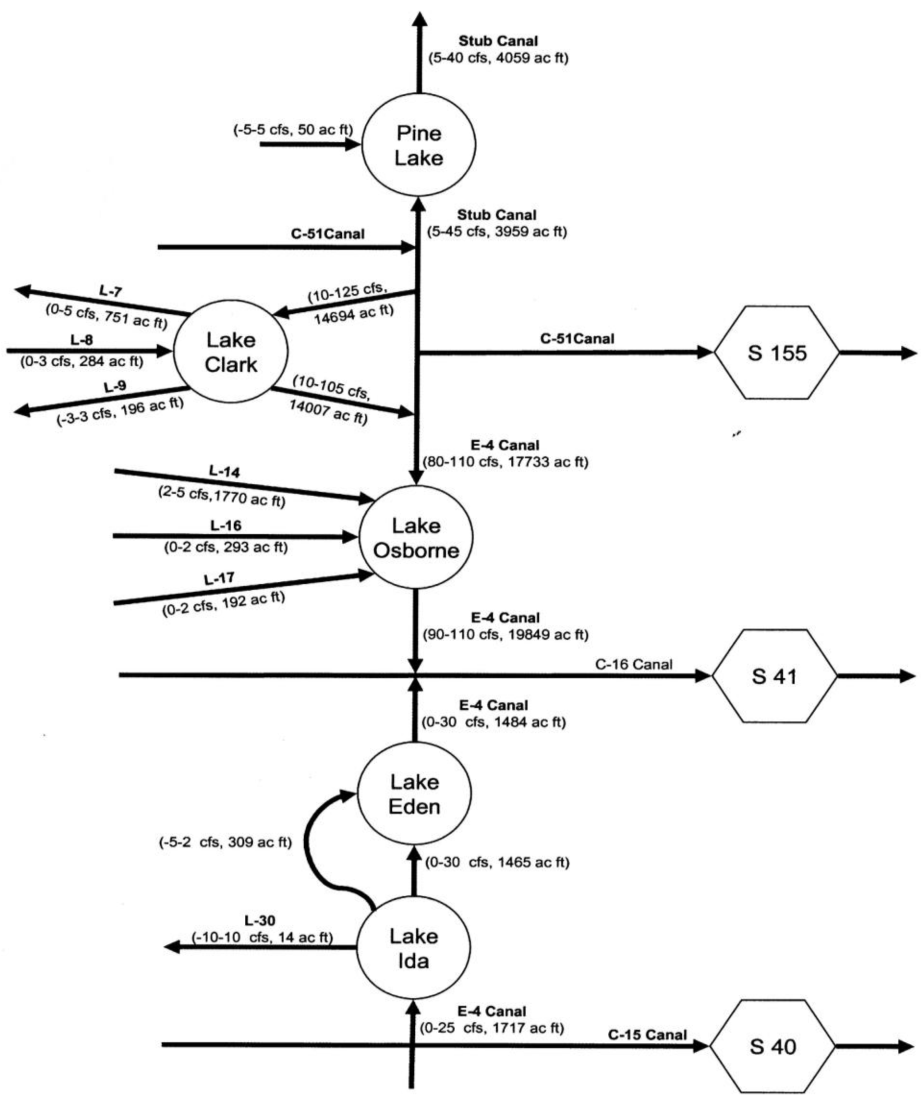
The pattern of flow of these canals can be a major factor in delivering nutrient laden water throughout the watershed and if a sufficient retention time is present, nutrients can be stored in the lakes sediments. Reference will be made to the ERD 2002 study with results of nutrient hydrologic loadings to each lake system. Re-suspension of the concentrated nutrient sediments can put these same nutrient back into the water column where they could increase algal blooms which are detrimental to the health and biotic balance of the lake. The hydrology for each of the four Chain of Lakes systems will be discussed below in the Lakes Discussion Section related to any impacts to water quality. The Chain of Lakes hydrology was not specifically investigated as a part of this study; therefore see the ERD report for additional information. The schematic flow charts Figures 2 and 3 below are from the 2002 ERD study and although the flow calculations (cfs) may not be representative of current conditions, the overall schematic diagram is an excellent view of the COL hydrologic characteristics during the wet and dry seasons.

Figure 2. Wet Season



Schematic of Water Flow Diagram (December-April 2001)

Figure 3. Dry Season



Schematic of Water Flow Diagram (May-July 2001)

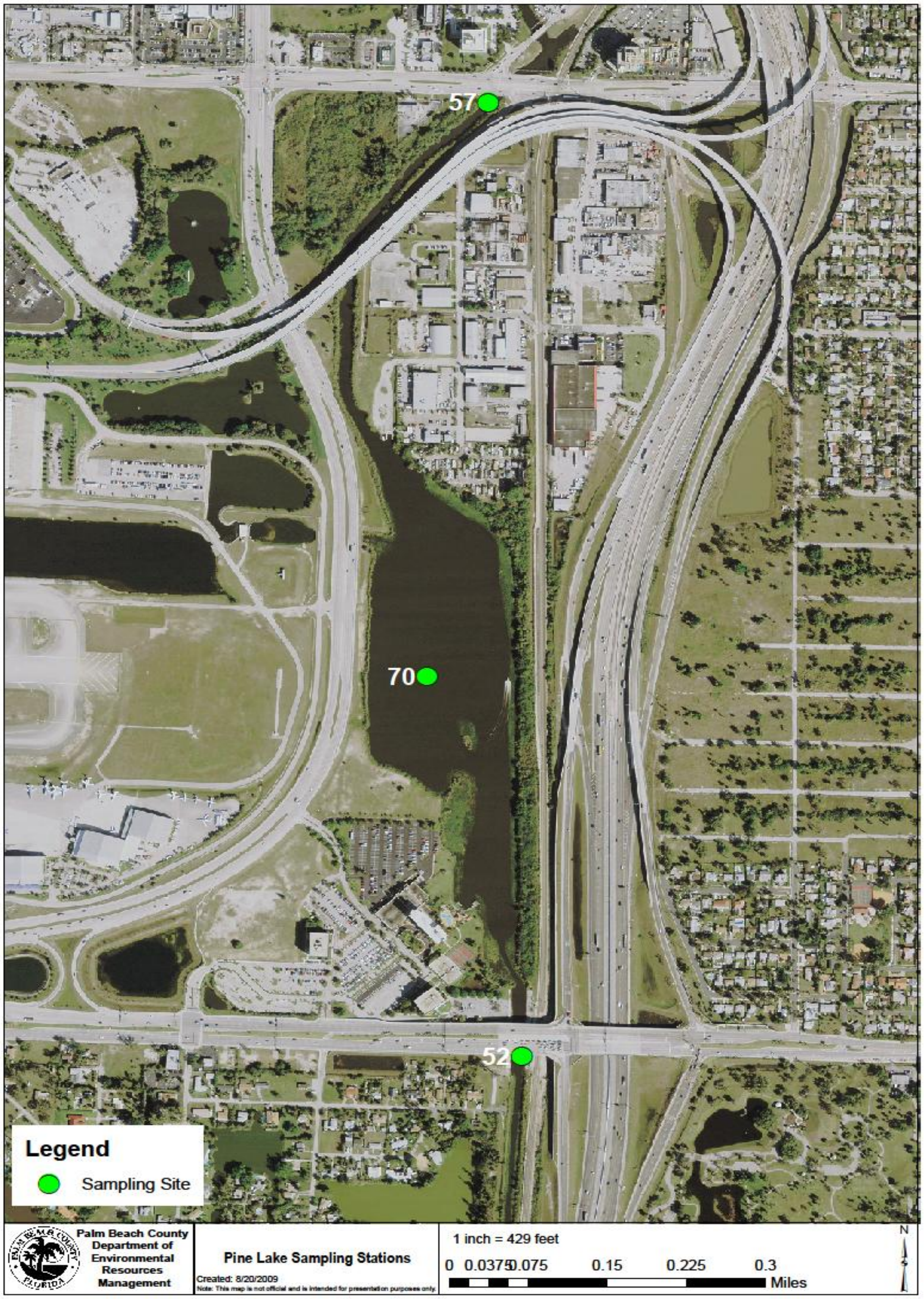
IV. Discussion of the Water Quality for the Chain-of-Lakes

Pine Lake

Pine Lake is the northern most lake in the Chain of Lakes system and lies within the boundaries of the C-51 east basin. The lake extends from Belvedere Road south to Southern Boulevard. Sampling stations are show in Map 2. Inflow and outflow to the lake primarily occurs through the Stub Canal which connects to the C-51 Canal. There is also a minor tributary from the airport in the northwest section of the lake. In a prior study, ERD 2002, has shown the primary source of nutrient input as the southern reach of the Stub Canal driven by flows from the C-51 Canal. Water Quality data statistics for 2006-2008 is below in Table 2.

Table 2: Pine Lake Water Quality Statistics (2006-2008)

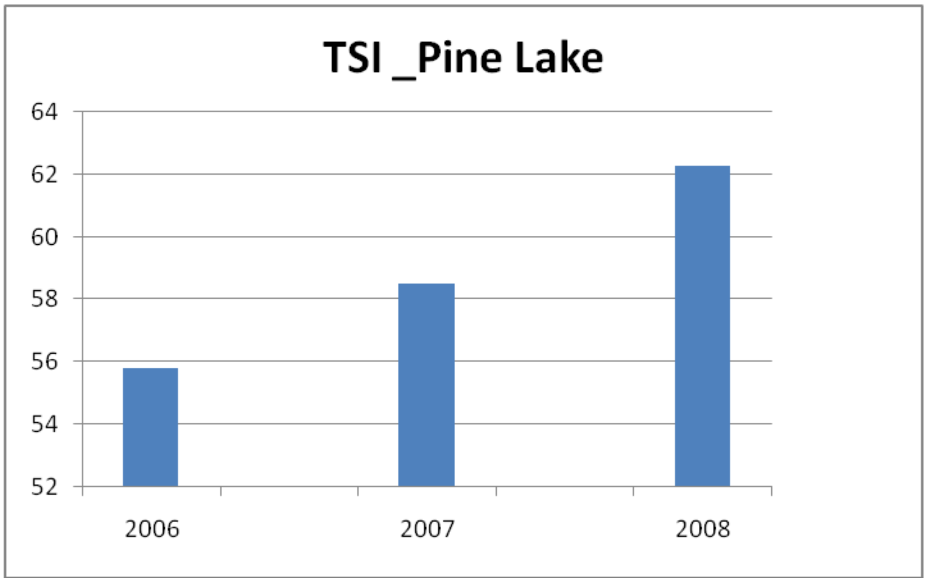
PARAMETERS (measurement units)	MEAN	STD. DEV.	MEDIAN	MIN.	MAX.
Total Nitrogen (mg/l)	1.097	0.487	0.995	0.420	2.50
Total Phosphorus (mg/l)	0.060	0.019	0.054	0.020	0.110
Dissolved Phosphorus (mg/l)	0.003	0.006	0.0001	0.000	0.016
Ammonia (mg/l)	0.048	0.052	0.040	0.00	0.208
Chlorophyll – a (mg/M^3)	24.2	12.2	23.0	4.2	60
Dissolved Oxygen(mg/l)	6.27	1.97	6.71	1.17	10.2
pH (S.U.)	7.50	0.148	7.48	7.26	7.78
TSS (mg/l)	6.7	3.48	6.9	0.00	12.0
Turbidity (NTU)	5.62	3.17	4.8	0.00	11.0
Fecal Coliform (cfu/ml)	825	1863	190	12	8000



Map 2. Pine Lake sampling stations.

In general, Pine Lake is pH balanced and relatively buffered. Nutrients values indicate the nitrogen and phosphorus are in the particulate forms and the readily available dissolved forms reduced. The TSI calculations for 2006, 2007, and 2008, show an annual increase: 2006 = 55.8, TSI 2007 = 58.5, and TSI 2008 = 62.3, see Figure 4. For Pine Lake the critical value corresponding to water quality impairment is 60. According to the IWR, lakes that show a TSI value of 60 or greater for any three years in a five year cycle, are considered nutrient impaired. Pine Lake in 2008 reached the TSI threshold of 60.

Figure 4. TSI Calculations for Pine Lake.



The data show Pine Lake is nutrient-balanced; therefore both TN and TP can have an equal effect on the system. Over the three year period TN has increased each year, while TP has decreased each year, see Figures 5 and 6, below. This may suggest nitrogen is the nutrient causing the TSI increase. The Chl-a concentration, which could indicate important disruptions of the ecosystems health, is highly variable with a range of 4.2- 60 mg/M^3. Values over 40 would be from major algal bloom but may only be a limited threat at this time. Future nutrient loading could increase eutrophication and algal blooms.

Measurement of fecal coliforms suggests a concern for human health issues. The mean value of 820 cfu and a range up to 8000 cfu shows several samples exceeds the State Water Quality Rule (and the IWR) of 400 cfu for a single discrete sample within 30 days. Although fecal coliforms can come from any warm bloodied animal, human pathogens may be present, and it has been established some animal pathogens can be transmitted between species including humans.

Dissolved oxygen concentrations were mostly good with a mean and median of 6.27 and 6.71, respectively. However, a number of exceedances of the Florida Water Quality Standard of 5.0 mg/l were measured. Dissolved oxygen concentrations must be adequate to support a healthy fishing population. Water bodies with dissolved oxygen concentrations below 5 mg/l on a frequent basis can lead to a classification of impaired, if a causative pollutant is found.

Figure 5. Pine Lake. Total Nitrogen in mg/l.

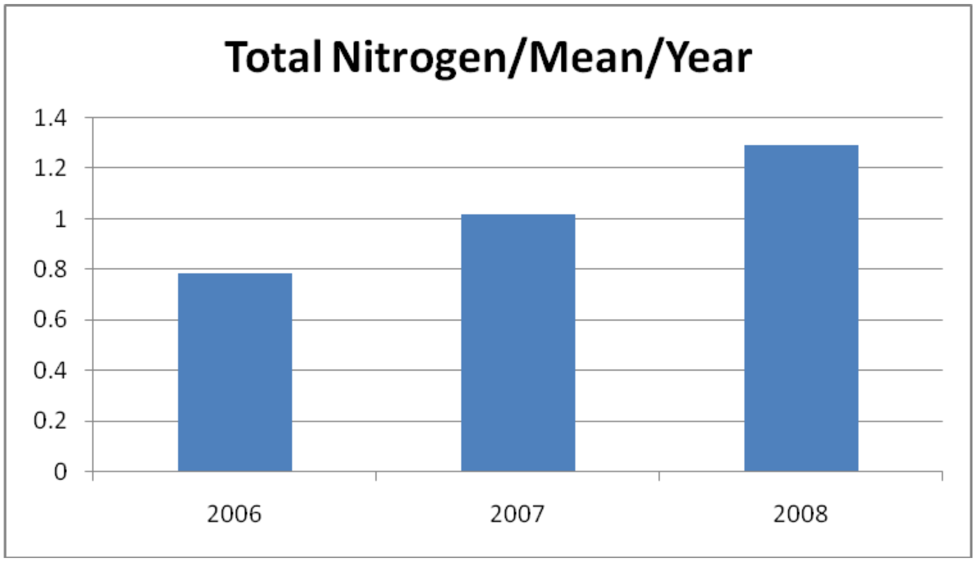
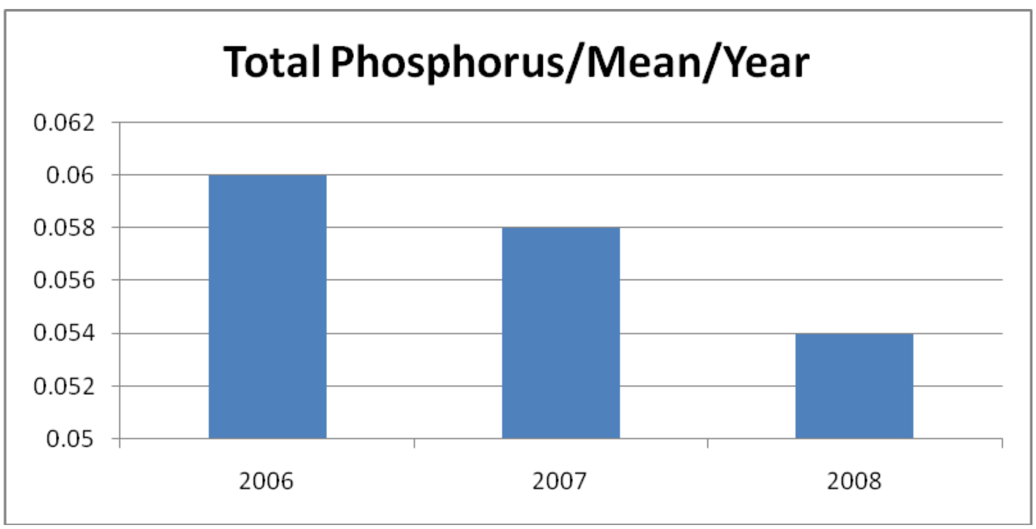


Figure 6. Pine Lake. Total Phosphorus in mg/l

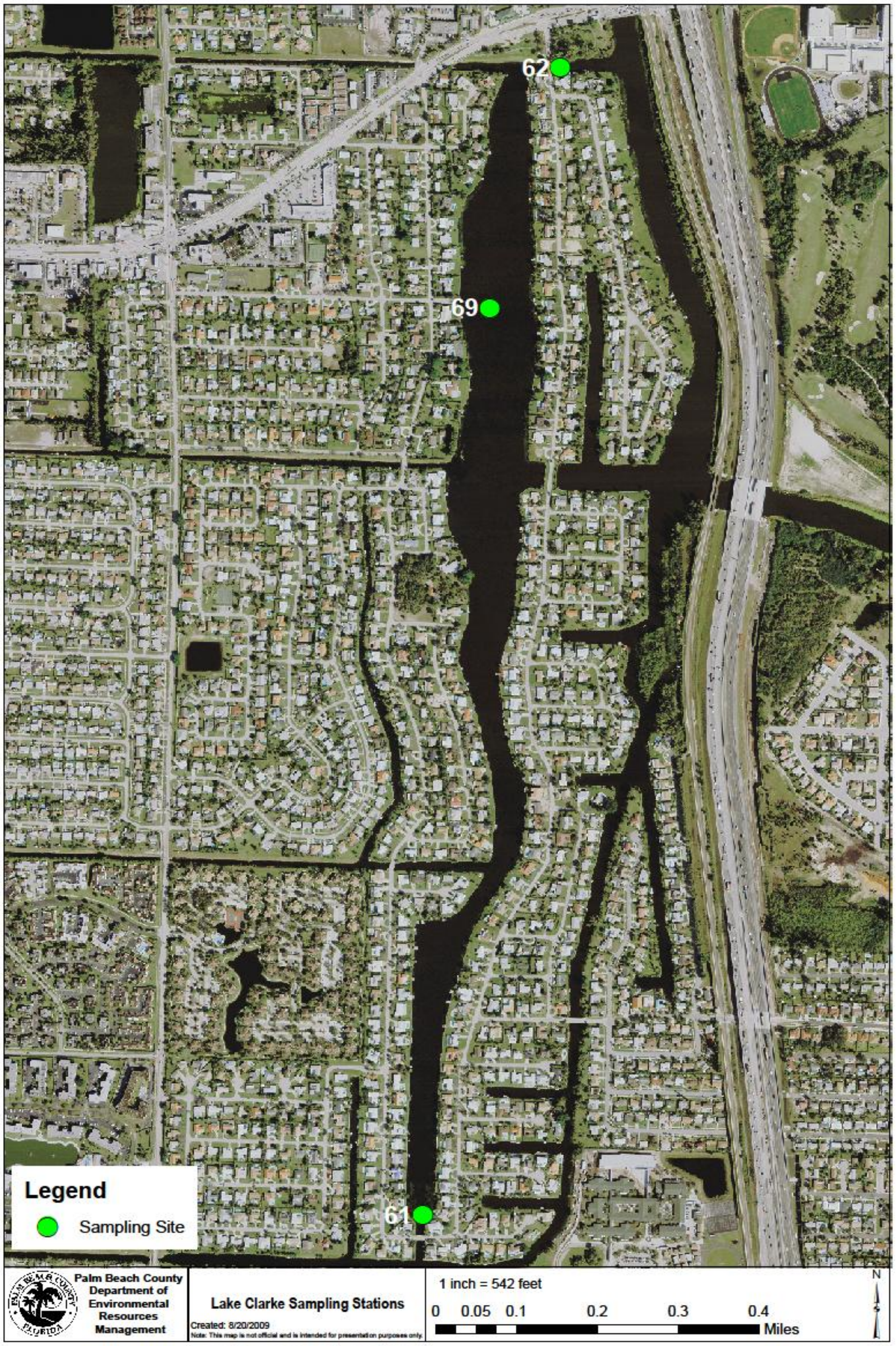


Lake Clarke

Lake Clarke is located south of Pine Lake and west of the C-51 and E-4 Canals. The water entering the lake originates from several interconnected canals, including a connection with the C-51 at the northern end and a connection to the E-4 at its southern end. Sampling stations are shown in Map 3. There are several small drainage pipes draining to the lake but their effect is minimal compared to the inputs from the C-51 and LWDD canals. A summary of water quality characteristics is below in Table 3.

Table 3. Lake Clarke Water Quality Statistics (2006-2008).

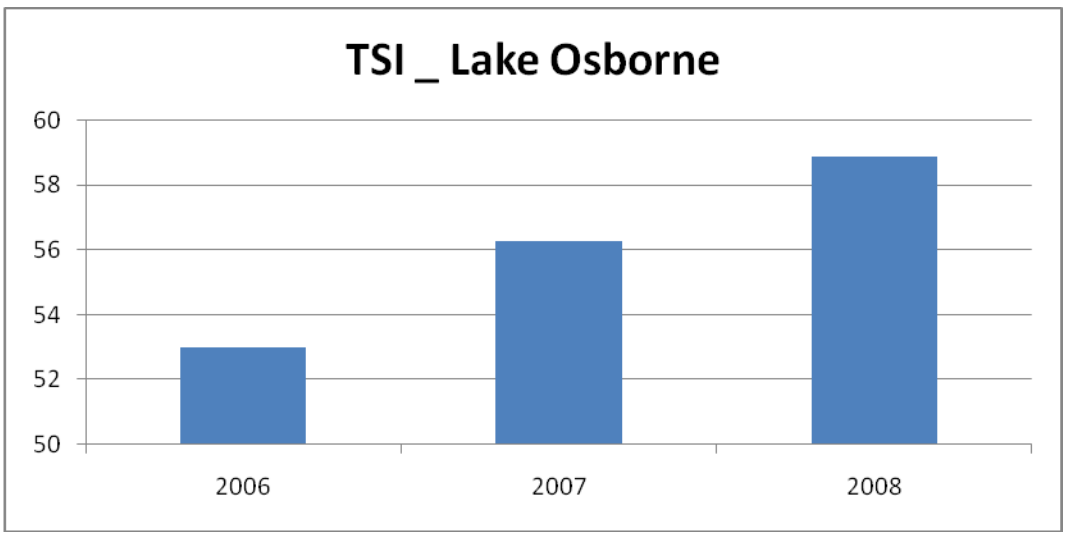
PARAMETERS (units)	**MEAN**	**STD. DEV.**	**MEDIAN**	**MIN.**	**MAX.**
Total Nitrogen (mg/l)	1.21	0.424	1.20	0.01	2.26
Total Phosphorus (mg/l)	0.65	0.02	0.062	0.02	0.124
Dissolved Phosphorus (mg/l)	0.004	0.010	0.004	0.00	0.032
Chlorophyll a (mg/M^3)	19.3	18.96	15.0	0.0	74.0
Ammonia (mg/l)	0.025	0.047	0.31	0.00	0.412
Dissolved Oxygen(mg/l)	7.53	1.56	7.44	4.94	11.08
pH (S.U.)	7.78	0.27	7.75	7.30	8.56
TSS (mg/l)	5.98	5.79	7.15	1	26.7
Turbidity (NTU)	4.95	3.42	4.7	1.3	16.2
Fecal Coliform (cfu/ml)	96.4	1094	165	1	3800



Map 3. Lake Clarke Sampling stations.

Lake Clarke is a pH balanced lake although on a few occasions the high range values approached the maximum state standard limit of 8.50. With mean values within a normal range with a low standard deviation this upper limit values are now a cause for concern. One high pH value coincided with an algal bloom which may explain this result as algae consume large amount of CO_2 in the process of photosynthesis which in turn reduces the amount of carbonic acid in the water and shifts the pH to a high value. Algal blooms as represented by the Chlorophyll a results were not of concern as mean and median values were relatively low, < 20 mg/M3, with rare blooms during the summer months. TSI values are all below the IWR Standard of 60, but the TSI has been increasing for every year of this study and could possibly reach 60 if the trend continues, and if nutrient loads are not reduced. See Figure 7, for TSI calculations.

Figure 7. TSI Calculations for Lake Clarke.



Lake Clarke is a nutrient balanced system so reductions of either TN or TP would slow or reverse the TSI trend. Results for total nitrogen show a slight increase since 2006, while total phosphorus has decreased in each year since 2006. Total nitrogen may be assumed to be the driving force for the TSI increases. Table 8 and 9, below represent the three year mean values for TN and TP, respectively.

The ERD study suggests nutrient loading as the greatest from the C-51 Canal. Water generally flows south through the lake and exits the south end towards the E-4 outfall. However, water has been occasionally observed to flow in the opposite direction, south to north, but this is a rare occurrence.

Figure 8. Lake Clarke. Total Nitrogen in mg/l.

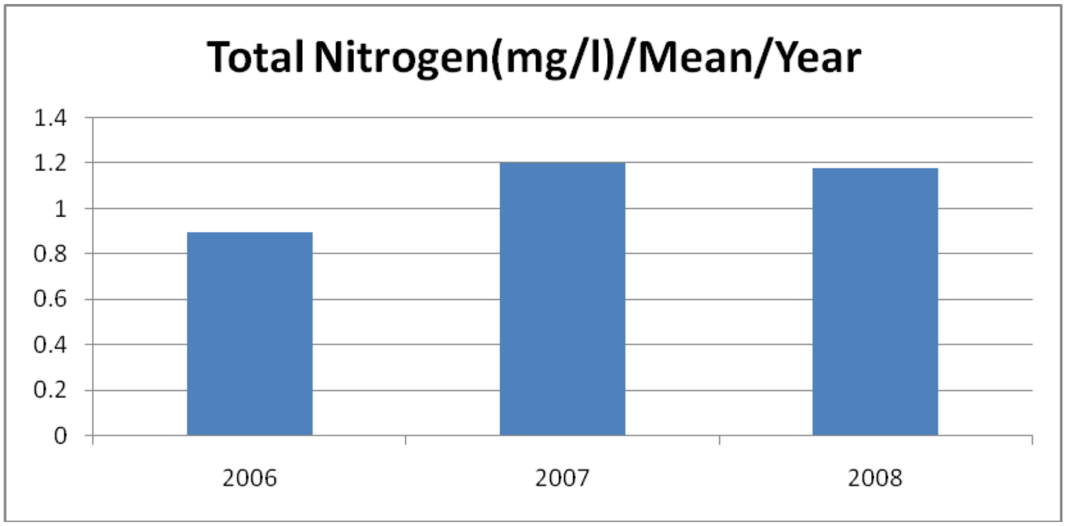
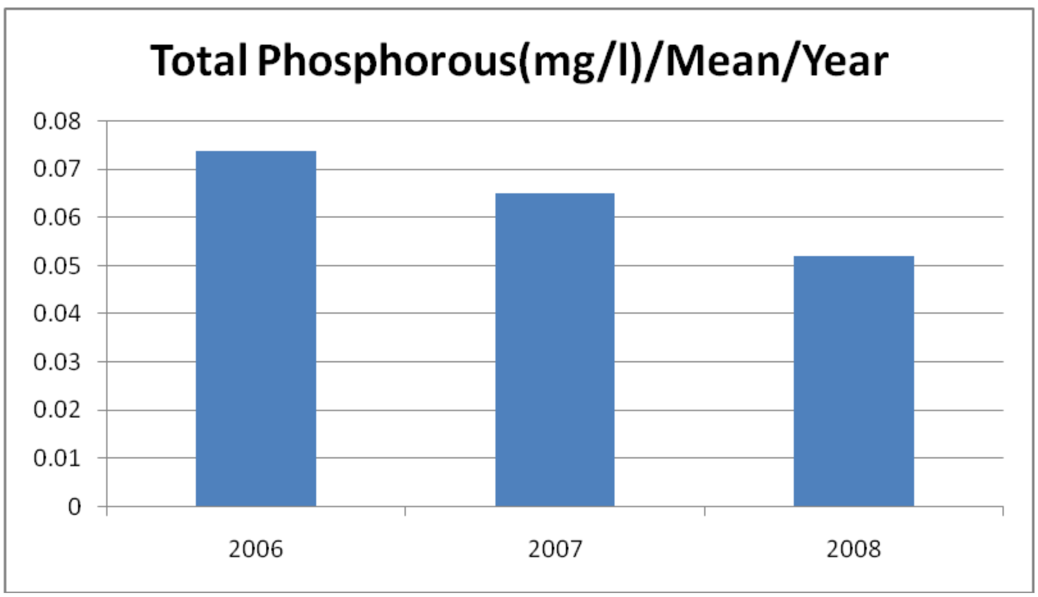


Figure 9. Lake Clarke. Total Phosphorus in mg/l.



Dissolved oxygen concentrations for the three years of collecting data indicate no violations of the 5 mg/l standard. Results are very good with a mean and median of 7.53 and 7.44, respectively. Dissolved oxygen concentrations had little variation from year to year and season to season. Fecal coliforms exhibit a wide range from 1 cfu to 3800 cfu's, with a standard deviation of 1094. As with Pine Lake the coliform concentrations are sporadic and more varied in the summer or the wet season.

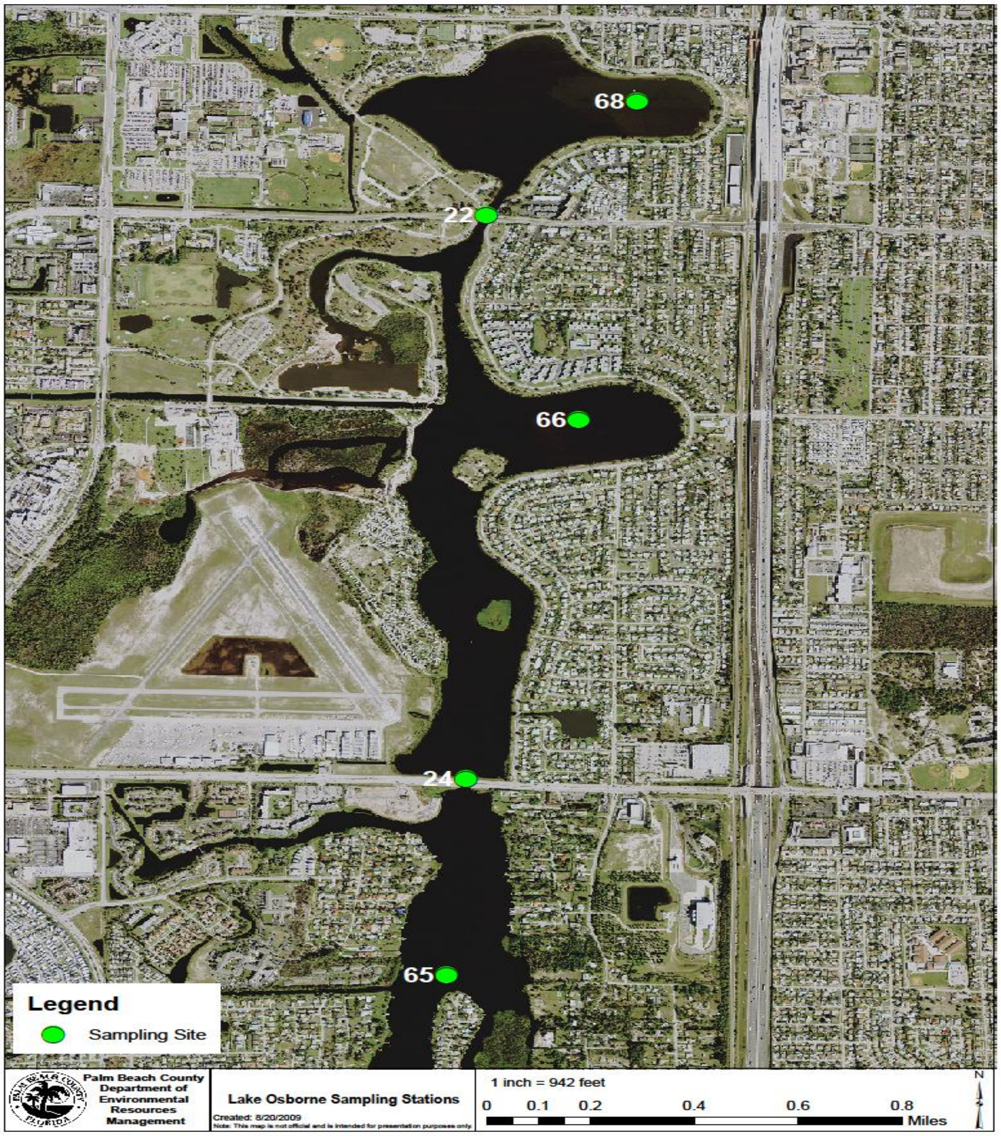
Lake Osborne

Lake Osborne is located south of Lake Clarke. Sampling stations are shown in Map 4. Technically Lake Osborne is in the C-16 basin. However, water flow can go north via the E-4 Canal to the C-51 Canal and out through the S-155 structure, or south through the E-4 Canal to the C-16 Canal and to tide by way of the S-41 structure. Three east-west LWDD lateral canals enter the lake from the west. Although water may go either north or south, the ERD study observed flow primarily from north to south. Although there are several small stormwater discharge structures with the lake system, the greater hydrologic inputs to Lake Osborne are the result of the E-4 Canal system and the LWDD lateral canals. Sampling stations are referenced on Map 4, and water quality data are shown in Table 4, below.

Table 4. Lake Osborne Water Quality Statistics, 2006-2008

PARAMETERS (units)	**MEAN**	**STD. DEV.**	**MEDIAN**	**MIN.**	**MAX.**
Total Nitrogen (mg/l)	1.172	0.974	1.03	0.413	1.88
Total Phosphorus (mg/l)	0.049	0.019	0.051	0.013	0.104
Dissolved Phosphorus (mg/l)	0.008	0.013	0.011	0	0.044
Ammonia (mg/l)	0.008	0.179	0.005	0.001	1.00
Chlorophyll a (mg/m^3)	18.4	18.3	14.0	1	88*
Dissolved Oxygen(mg/l)	7.93	1.09	8.17	4.27	11.10
pH (S.U.)	7.94	0.32	8.03	7.27	8.67
TSS (mg/l)	1	4.4	2.9	1	13.6
Turbidity (NTU)	3.06	2.12	3.30	1	10.3
Fecal Coliform (cfu/ml)	23	2434	20	0	13600

*Data Outlier July 2007.



Map 4. Sampling stations.

Lake Osborne is relatively pH buffered. Mean and median values are 7.94 and 8.03, respectively, which is at the upper end for Florida lakes. There were three state standard violations of values greater than 8.5. The lake data does not indicate there is a serious pH problem as these higher than normal pH numbers correspond with summer time algal blooms and elevated Chlorophyll a as explained previously for Lake Clarke.

TSI values have dramatically increase in the past three years, see figure 10. This is the Chain of Lakes trend so far as TSI values have increased in the other lakes discussed above. Lake Osborne shows the greatest increase from 44.2 in 2006 to 60.2 in 2008. Total nitrogen concentrations have also increased each year and most likely is the driving force for the TSI increase as total phosphorus concentrations have remained constant. Both TN and TP concentrations are shown graphically below in Figures 11 and 12. Typically water flows north to south in Lake Osborne. Nutrient loadings enter the lake as a result of the north to south inflow of the E-4 Canal, and exit the lake in the south with the continuation of the E-4 Canal.

Figure 10. TSI Calculations, Lake Osborne.

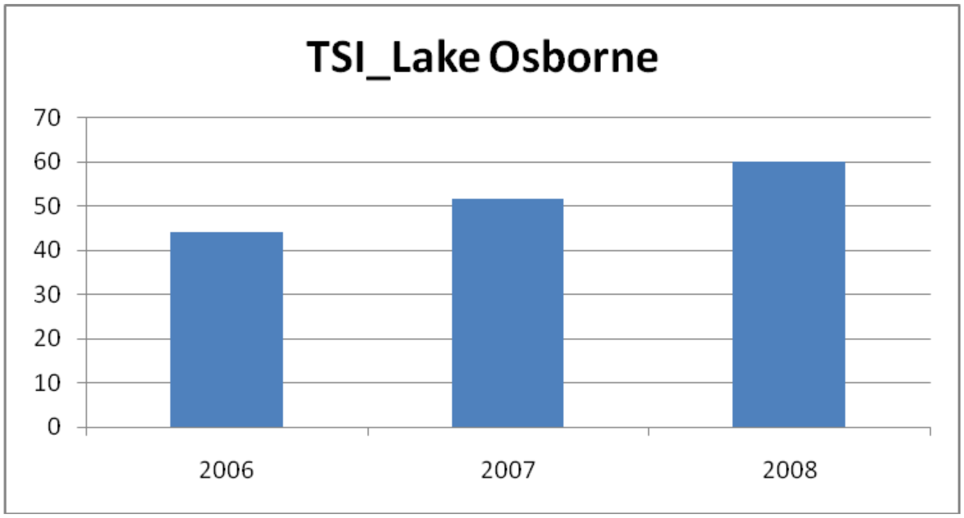


Figure 11. Lake Osborne. Total Nitrogen in mg/l.

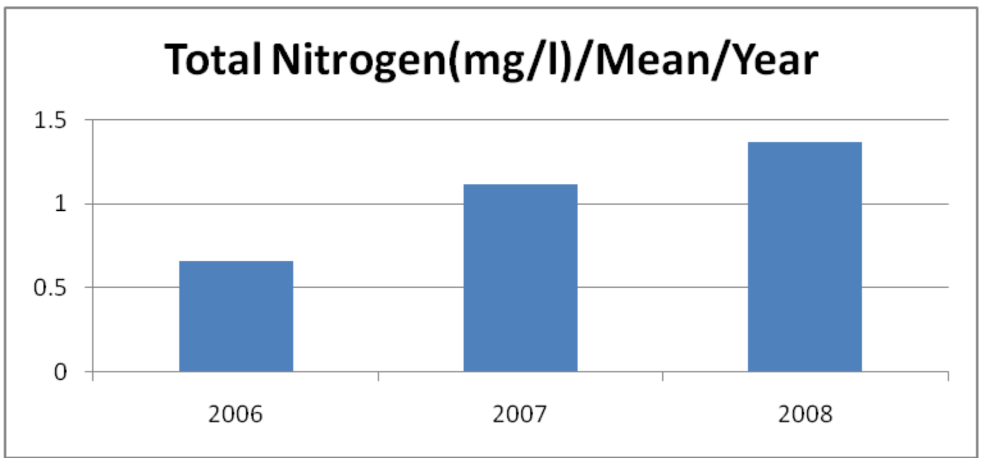
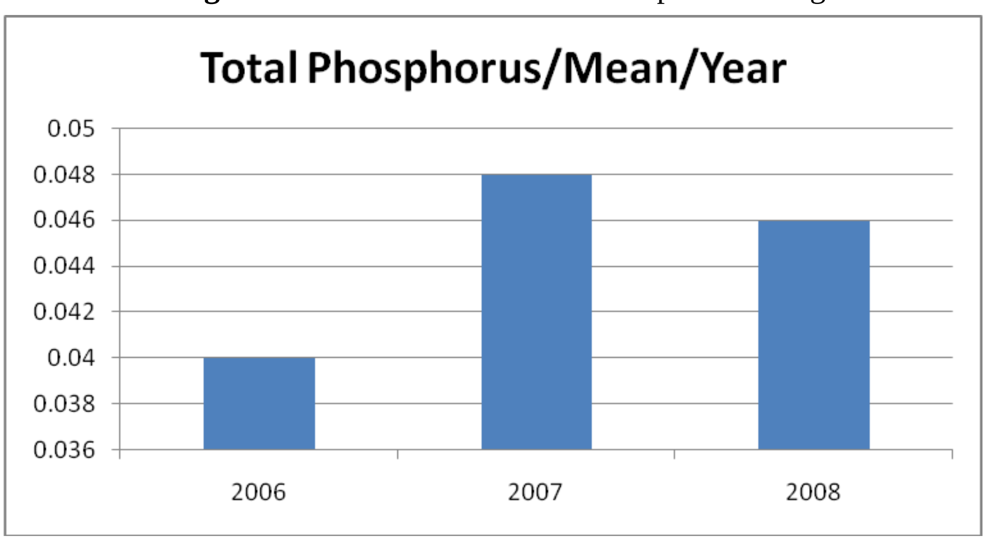


Figure 12. Lake Osborne. Total Phosphorus in mg/l.



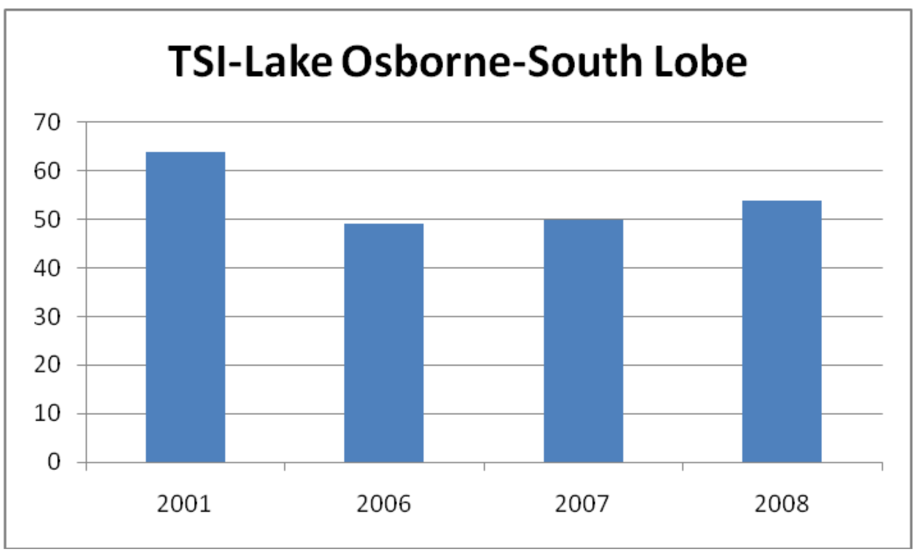
Chlorophyll a concentrations were generally moderate with only a few elevated concentrations of 40 mg/m^3 or higher. These possible algal bloom concentrations usually occurred during the summer months but did not seem to adversely affect dissolved oxygen or pH values. pH values were relatively high year around. Based on the TSI and nutrient concentrations, nitrogen reduction may be to key to water quality improvement.

Dissolved oxygen mean and median concentrations were 7.93 and 8.17, respectively. However, several violations of the state standard for dissolved oxygen were observed. In general most dissolved oxygen values were in the good range (7-8 mg/l) for aquatic life throughout the three years of data collecting.

Fecal coliform concentrations were again very sporadic with several extremely high concentrations that fail the state standard of 400 cfu/ml for a single sample event. The highest coliform concentrations for the Chain of Lakes were in Lake Osborne, although the mean was lower than Pine Lake and Lake Clarke.

Prior to commencement of the current monitoring program for the Chain of Lakes in 2006, a muck removal project was completed in the south lobe of Lake Osborne. Nutrient rich sediments can lead to elevated nutrient concentrations in the water column, under certain conditions. The TSI value for 2001 was obtained from the 2002 ERD Report. It would appear that the muck removal improved water quality in the south lobe.

Figure 13. Lake Osborne South Lobe 2001

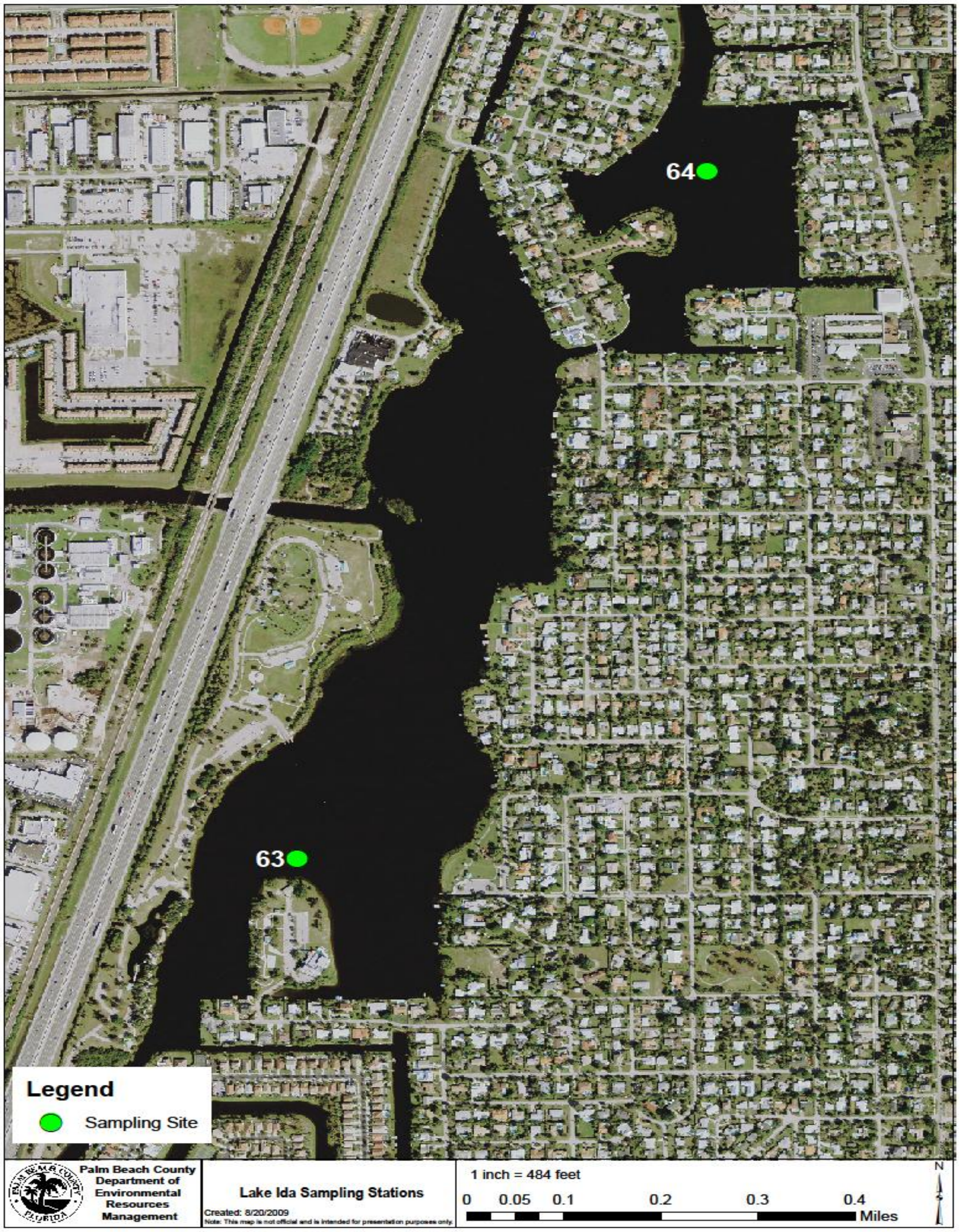


Lake Eden and Lake Ida

The two lakes are evaluated as one system due to their proximal location and hydrology. Both are located at the southern end of the Chain of Lakes system. Sampling Stations are shown in Map 5. Lake Eden is the northern most lake and connects to Lake Ida at its most southern end. Lake Eden's hydraulic flow varies between wet and dry season. It has been observed that water flows north to south during the dry season and reverses flow, south to north, during the wet season. Direct stormwater inputs occur in both lakes but have a minimal effect in the overall loading concentrations to the lakes, (ERD 2002). As both lakes are essentially acting as one system the water quality data have been combined, see Table 5.

Table 5. Water Quality Statistics for Lakes Eden and Ida.

PARAMETERS (units)	**MEAN**	**STD. DEV.**	**MEDIAN**	**MIN.**	**MAX.**
Total Nitrogen (mg/l)	1.17	0.333	1.10	0.670	1.90
Total Phosphorus (mg/l)	0.09	0.02	0.09	0.04	0.15
Dissolved Phosphorus (mg/l)	0.020	0.020	0.019	0	0.079
Ammonia (mg/l)	0.016	0.039	0.028	0	0.09
Chlorophyll a (mg/m^3)	29.7	18.9	31.2	2.0	77.0
Dissolved Oxygen(mg/l)	8.71	1.21	8.40	6.62	11.37
pH (S.U.)	7.92	0.039	7.99	7.24	8.75
TSS (mg/l)	1.6	3.2	5.8	0	11.1
Turbidity (NTU)	2.4	2.3	3.6	1	7.5
Fecal Coliform (cfu)	17	52	30	0	340



Map 5. Sampling stations.

The lakes are pH balanced and buffered although twice during the three years pH was above the state standard of 8.5. These events were rare and typical of the several high chl-a samples indicating a major algal bloom.

Lake Ida and Eden are on the FDEP Impaired Waters list for excessive nutrients as indicated by TSI values over 60. During this study one sample was taken from each lake bimonthly and the TSI calculation made using both samples. In two of the three years the TSI was greater than 60, see Figure 14. According to the TSI calculations the two lakes are nitrogen limited. Therefore, nutrient load reductions and water quality improvement, necessary because of anticipated Total Maximum Daily Load (TMDL) requirements should focus on the TN source(s).

Although TN and TP do not seem to be extremely high for these lakes, nutrient inputs or internal recycling of nutrients have contributed to the TSI Rule violation. Nutrient input to the lakes is primarily from the LWDD E-4 canal (flowing south) and the L-30 Canal which enters the west side of Lake Ida. According to the ERD report Lake Eden receives its major nutrient loading from E-4 Canal, again flowing south. Internal nutrient re-suspension and recycling may also play a part in the elevated TSI levels. Below are the TN and TP yearly mean data in Figures 15 and 16, respectively. Note that the TP concentrations are high relative to the other lakes in the chain, and that the TN is about average for the Chain of Lakes system. This indicates that because we have the high concentration of TP, nitrogen becomes the limiting factor and any increase in nitrogen loadings will have a negative impact on water quality, resulting in higher TSI's and algal blooms. Limiting and reducing nitrogen sources would benefit these lakes.

Figure 14. TSI Calculations for Lakes Eden and Ida Combined.

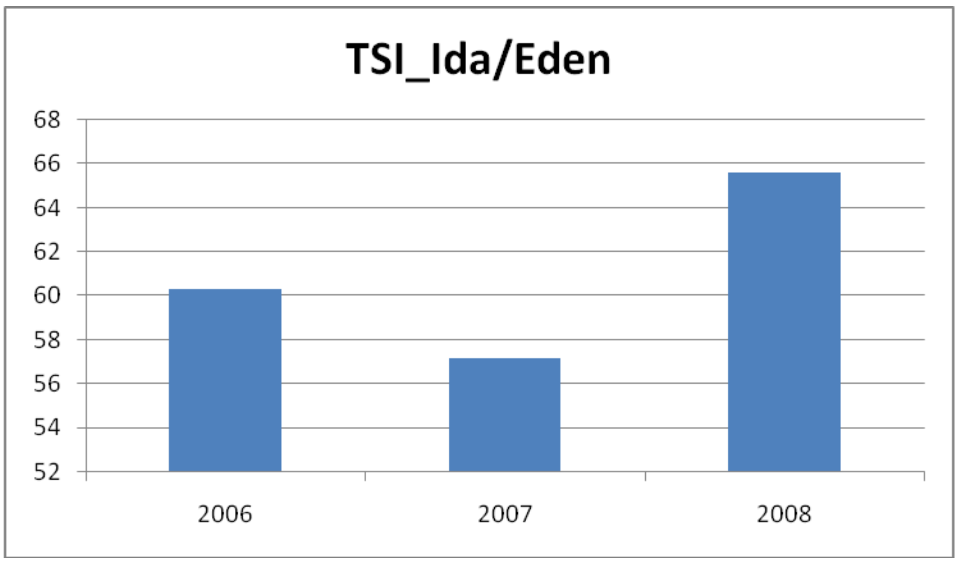


Figure15. Lakes Eden and Ida. Total nitrogen in mg/l.

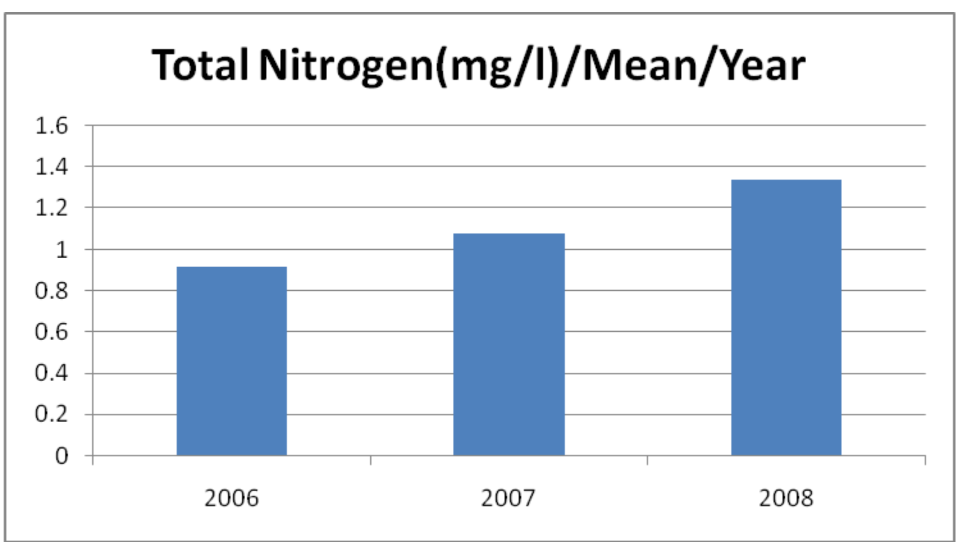
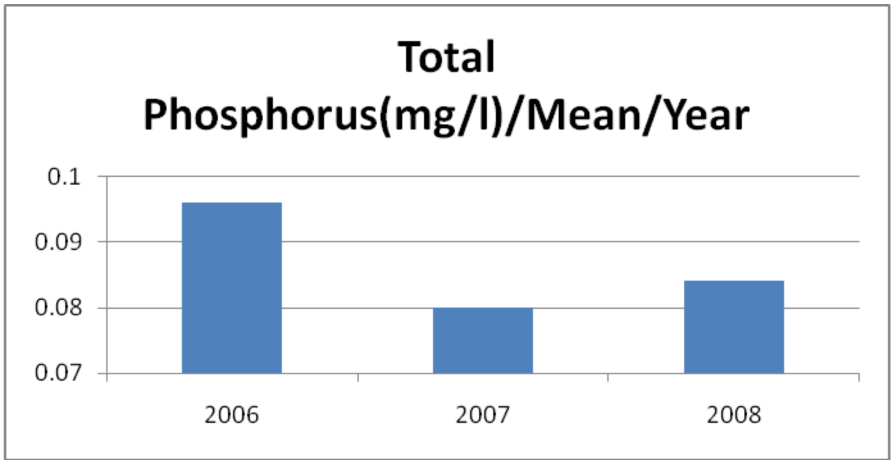
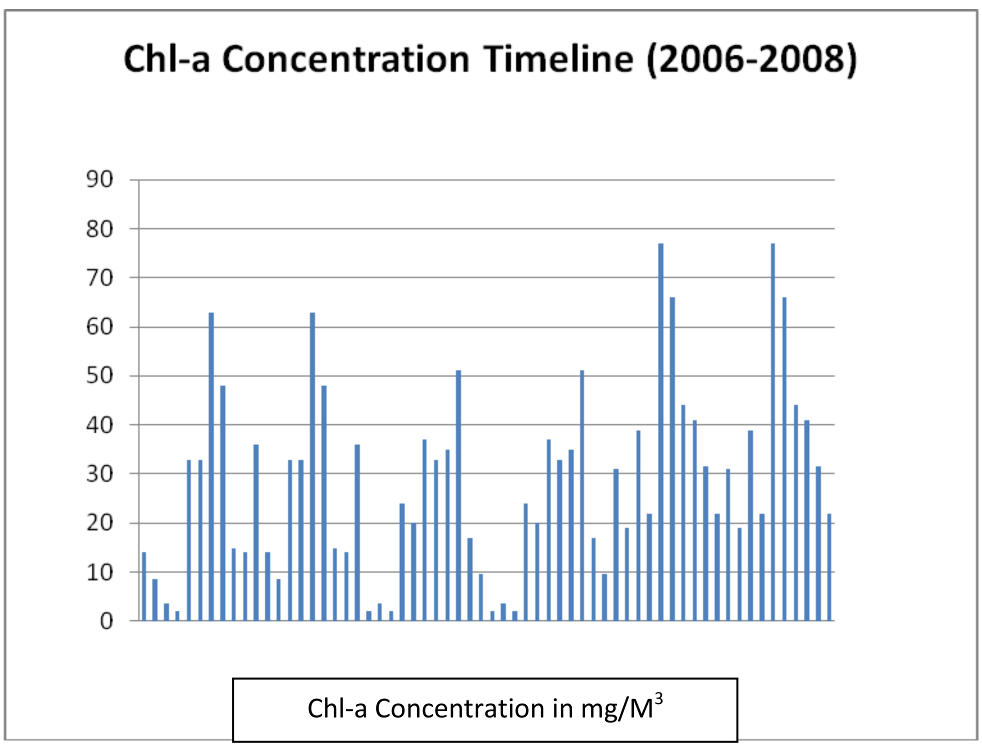


Figure 16. Lakes Eden and Ida. Total phosphorus in mg/l.



Chlorophyll a concentrations are also the highest in Eden and Ida compared with all the other lakes, with a mean of 29.7 mg/M^3. Figure 17, demonstrates the concentration timeline for chlorophyll a from 2006 to 2008. Notice the increasing concentrations over 40 mg/M^3 which indicate algal blooms. The majority of the blooms occurred during the wet season. This is a typical result from elevated nutrients (TP) and driven by an increasing input of the limiting factor (TN) which cause an imbalance producing algal blooms. The lakes also had one of the highest chl-a concentrations (77 mg/m3) which is approaching the category of a catastrophic algal bloom. These blooms are not representative of a well balanced and healthy lake system.

Figure17. Chlorophyll-a Concentration Timeline (2006-2008). Lakes Eden and Ida.



Typically, when there is a TSI 60 or greater, major algal blooms are persistent as we see in the Lake Eden and Ida data. That usually means DO concentrations will undergo severe fluctuations and usually a period of DO depletion. The depletion of DO is the true negative effect of algal bloom in many instances. However, in Eden and Ida there have been no extreme variances in the DO concentrations. DO consistently remains high with a mean concentration of 8.71mg/l and the lowest recorded concentration of 6.62 mg/l. Data may indicate that the blooms are being sustained for a period of time and not subject to the sudden rise and then immediate bloom crashes that can produce the typical negative impacts.

Coliform concentrations for the three sampling years indicate that there are no acute or chronic health impacts to the lakes. All sample concentrations of fecal coliforms are below the state standard of 400 cfu/100ml for a one day monthly sample. The mean and median concentration for Eden and Ida are 17 and 30 cfu/100ml, respectively.

V. Conclusions

The Tropic State Index or TSI is a universal, well established water quality tool used by lake scientists. The FDEP uses the TSI as a critical statistic in identifying nutrient impairment for freshwater lake systems. Nitrogen and phosphorus are the two major nutrients that cause lake impairment due to increasing lake eutrophication. Eutrophication leads to an unhealthy lake and ultimately a "dead" system in terms of a healthy balance of biota and inhibits human recreational use.

Therefore, the general ecological alarm based on the three years of data is the increasing eutrophication of the lakes within the chain. Lake Ida and Eden are on the current FDEP Impaired Water List due to excessive nutrients as measured by the TSI. Pine Lake and Lake Osborne reached the TSI critical value of 60 in 2008. All lakes in the chain have shown a trend of increasing TSI values since 2006. Although nitrogen has been identified as the nutrient of concern for Eden and Ida, the critical nutrient(s) of concern has not yet been identified for the other three lakes. Chlorophyll a is one of the three factors in calculating the TSI, but it is an important metric in its own right. The Chlorophyll a concentrations can give us estimation of the algal standing crop and over time and can be used as a standalone indicator of eutrophication. Algal blooms can reduce or eliminate dissolved oxygen in the water column which will suffocate the fish and other organisms. Additionally, large blooms of extended duration will reduce sunlight penetration and can kill beneficial plant life that is extremely important to the health of any aquatic system. The lakes in the chain are showing periodic algal blooms (concentrations over 40 mg/m^3), but as nutrients input increase it is expected that the blooms will increase in frequency, duration, and concentration. Although it's currently a rare event certain types of algal blooms can release a water soluble toxin in the water that can be harmful to wildlife and humans. These "toxic" algae have been identified in south Florida waterbodies over the last 20 years and are of special concern to anyone concerned about water quality.

Dissolved oxygen concentrations overall are generally satisfactory at the present time and support a healthy biology in the lakes. Although as nutrient loadings increase, the DO concentrations could be a first line indication of dramatic eutrophication as algal blooms increase and cause disruption of the biological communities. This report shows dissolved oxygen concentrations at about the same time period during the day. Oxygen concentrations can vary greatly over a 24 hours cycle and the State water quality criteria are based on this reality. Diurnal studies of the dissolved oxygen concentrations could provide useful information as the lakes continue to be impacted by increasing nutrients inputs.

Fecal coliform, especially in the upper lakes, have shown excessive sporadic concentrations over the three years of this project. The temporal pattern for the coliform data indicates a source that is spontaneous and irregular. One strong possibility is transient populations of aquatic birds. Many studies in Florida have indicated the causative agent for extremes in fecal coliform concentrations on bird populations. Because there can be a human health risk associated with fecal coliforms regardless of the source, a more definitive study of coliforms may be warranted especially due to the large number of lakeside residences and recreation activities within the lakes.

Basic physical characteristics, including pH, TSS, turbidity, show values within the normal and ideal range for lakes.

VI. Recommendations:

Sampling should continue to provide the data need to monitor Lake Ida and Eden as it is currently on the Impaired Waters List developed under the Impaired Waters Rule (IWR), and the County and FDEP will need additional data for TMDL development and implementation of the TMDL Basin Action Plan.

Monitoring of the three northern lakes needs to continue to assess the increasing nutrient loading trends that is driving the different lake TSI's to the potential of being classified impaired by the IWR, especially Lakes Osborne and Pine.

Additional monitoring stations should be added if costs and staff time can be guaranteed to evaluate the source of the nutrient loadings, i.e., canals and tributaries. Diurnal oxygen concentration monitoring should be conducted on all lakes randomly during the wet and dry seasons. This source sampling would provide the additional data that is necessary for a Basin Action Plan to insure fairness and success for all parties that would be affected by the TMDL requirements.

Fecal coliform sampling should be more aggressive in the identification for the coliform source on each lake. Although the temporal evaluation of current data does not indicated any potential health related issue, the sporadic extremely high bacterial counts, e.g., 13600 cfu/100ml, represent a concern for future human health concerns.

Since the C-51 Canal was previously identified as the primary source of nutrient input for Lakes Osborne, Clarke and Pine, measures to reduce this loading must be pursued.